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SPECTROSCOPIC DETERMINATION OF THE PHYSICAL CONDITIONS IN HOT OPTICALLY THIN SOURCES

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Spectroscopic Determination of the Physical Conditions in Hot, Optically Thin Sources

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Nancy S. Brickhouse (Principal Investigator)

November 13, 2001

This annual report covers the period from Oct 1, 2000 to Sep 30, 2001.

The Astrophysics Plasma Emission Code and Database (APEC/APED), developed in part under this grant, have been upgraded to Version 1.1 (see http://asc.harvard.edu/atomdb) and are now beginning to be used outside our research group in applications to X-ray spectral data from Chandra and XMM-Newton (e.g. Huenemoerder et al. 2001, ApJ, 559, 1135; Xu et al. 2001, astro-ph0110013). These models represent the best theoretical data currently available and are reasonably complete below about 30 Å.

Stellar coronae are being used to benchmark the atomic data in APED as part of the Emission Line Project. Initial results suggest that the models for most of the strongest lines are in good agreement with the observations, including the H-like and He-like emission from dominant elements and the Fe L shell emission, both near 1 keV and in the EUV near 100 eV. At this point in time, we define "good agreement" at the level of accuracy expected from the atomic physics, $\sim 20 - 30$ %. In order to benchmark the spectral models beyond the canonical theoretical accuracy, we are working closely with the Chandra gratings calibration group to ensure that we are using the optimal calibration, primarily effective areas and line response functions.

There are numerous remaining issues. Below 30 Å: inaccurate wavelengths of weaker lines; incompleteness of the weaker line emission, affecting the measurement of diagnostic lines in the presence of real and weak-line ("pseudo-") continuum (Brickhouse 2001a); and, the inaccuracy of collisional data under non-equilibrium ionization conditions. For example, we have demonstrated that the Ly_α/Ly_β line ratio may be uncertain by as much as 30% below the ionization equilibrium temperature, rather than the 10% often claimed to be the accuracy of the calculations (Smith et al. 2001). We have also found that previous codes (Raymond-Smith and MEKAL) were not producing the correct high temperature limits for important Lyman series lines.

For the softer X-rays, collisional data are being calculated for L shell emission from O, Ne, Mg, Si, S, Ar, and Ca up to principal quantum number

n=5. Many of these atomic rates have never been available in the public domain. It is clear from the early Chandra LETG Emission Line Project spectra between 30 and 90 Å that line blending is a serious concern. With reasonably complete models in hand, we will begin to make serious headway in this spectral band. As an example preliminary tests on the lines of Fe XV and XVI suggest that more than half of the strongest diagnostic lines are significantly blended (Campbell & Brickhouse 2001).

Access to the spectral models and atomic data in APED/APEC is remarkably improved under the new CXC software release CIAO 2.2. The GUIDE package in the *Sherpa* fitting engine allows the user to list model lines for identification, get estimates of relative line strengths, store atomic data in a useful format and find the literature citations to the atomic data source (see http://asc.harvard.edu/ciao/threads/guide.thread.html). APEC models are also available in the MIT package ISIS and through the Goddard package XSPEC.

We continue to pursue numerous collaborations to help produce and test atomic data for X-ray spectroscopy. For example, the Capella data from the Emission Line Project suggest that the models for the strongest line of Fe XVII are incorrect at the 30% level (far more than one might expect). While the discrepancy between theory and observation may not be as bad as had been thought from solar observations, the confirmation of the problem with laboratory measurements is an important step toward understanding how to improve the theory (e.g. Laming et al. 2000).

The ELP collaborations are also producing interesting new results about the structure and abundances of cool star coronae. Early results from cool stars suggest that coronal structures of differing densities and temperatures exist on the same system. While the literature already contains conflicting results on the same systems from different authors and using different instruments, we have shown that the observations are consistent with each other if the proper treatment of weak lines is used (Brickhouse 2001a). The determination of accurate relative abundances requires high levels of confidence in the models of the ionization balance. We are beginning to pursue these tests with the Capella data.

A comprehensive analysis of the EUVE observations of stellar coronae is submitted for publication (Sanz-Forcada, Brickhouse, & Dupree 2001c). This work shows the diversity of emission measure distributions as a function of stellar activity, while also demonstrating the lack of association of dominant

patterns with stellar type or multiplicity of the system. Meanwhile, the physics of active region formation has been explored through new X-ray Doppler imaging studies of the rapidly rotating system 44i Boo (Brickhouse, Dupree, & Young 2001).

Dr. John Raymond, Dr. Duane Liedahl, and Dr. Randall Smith continue to work closely as collaborators on this project. We are currently advertising for a postdoctoral scientist to continue the emission line studies and make improvements to the plasma code and atomic database.

Publications and Presentations during the Reporting Period

Ayres, T. R., Brown, A., Osten, R. A., Huenemoerder, D. P., Drake, J. J., Brickhouse, N. S., & Linsky, J. L. 2001, Chandra, EUVE, Hubble, and VLA Multi-Wavelength Campaign on HR 1099: Instrumental Capabilities, Data Reduction, and Initial Results, ApJ, 549, 554

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Brickhouse, N. S. 2001b, EUVE and Chandra: The Emission Line Project Connection, in Proceedings of the Workshop Continuing the Challenge of EUV Astronomy: Current Analysis and Prospects for the Future, NASA, in press

Brickhouse, N. S., Dupree, A. K., & Young, P. R. 2001, X-ray Doppler Imaging of 44i Boo with Chandra, ApJ Letters, accepted

Brickhouse, N. S., Smith, R. K., Raymond, J. C., & Liedahl, D. A. 2000, The Astrophysical Plasma Emission Code, HEAD, 32.2701, Honolulu, HI

Campbell, S., & Brickhouse, N. S. 2001, The Measurement of Fe XV and Fe XVI Line Diagnostics in Capella with the Chandra LETG, Report for SAO Summer Intern Program, SAO

Drake, J. J., Brickhouse, N. S., Kashyap, F., Laming, J. M., Huenemoerder, D. P., Smith, R. K., & Wargelin, B. J. 2000, ApJ, 548, L81

Drake, J. J., Brickhouse, N. S., Kashyap, F., Smith, R. K., & Wargelin, B. J., Laming, J. M., Huenemoerder, D. P. 2000, Enhanced Neon in the Coronae of HR 1099, HEAD 32.4205, Honolulu, HI

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Kink, I., Laming, J. M., Takacs, E., Porto, J. V., Gillaspy, J. D., Silver, E., Schnopper, H., Bandler, S. R., Barbera, M., Brickhouse, N., Murray, S., Madden, N., Landis, D., Beeman, J., & Haller, E. E. 2001, Analysis of Broadband X-ray Spectra of Highly Charged Krypton from a Microcalorimeter Detector of an Electron-Beam Ion Trap, Phys. Rev. E, 63, 549

Laming, J. M., Kink, I., Takacs, E., Porto, J. V., Gillaspy, J. D., Silver, E. H.l, Schnopper, H. W., Bandler, S. R., Brickhouse, N. S., Murray, S. S., Barbera, M., Bhatia, A. K., Doschek, G. A., Madden, N. Landis, D., Beeman, J., & Haller, E. E. 2000, Emission Line Intensity Ratios in Fe XVII Observed with a MicroCalorimeter on an Electron Beam Ion Trap, ApJ, 545, L161

Mauche, C. W., Brickhouse, N., Howell, S., Hurwitz, M., Liedahl, D., Mukai, K., Raymond, J., Sirk, M., & Szkody, P. 2000, Simultaneous Chandra, EUVE, and RXTE Observations of the Intermediate Polar EX Hydrae, HEAD 32.4506, Honolulu, HI

McLaughlin, B. M., Kirby, K. P., Smith, R. K., Brickhouse, N. S., & Liedahl, D. A. 2001, Electron Collisional Excitation of the $1s^2 2s^2 2p^3$ ($^4S^0_{3/2}$,$^2D^0_{5/2,3/2}$,$^2P^0_{3/2,1/2}$) Fine-Structure Levels in Fe^{18+} Ions, *J. Phys. B*, submitted

Safronova, U. I., Vasilyev, A. A., & Smith, R. K. 2000, Satellite Dielectronic Spectra Created from Autoionizing 2lnl' and 1s2lnl' States with n=4-5, Can. J. Phys., 78, 1055

Sanz-Forcada, J., Brickhouse, N. S., & Dupree, A. K. 2001a, Extreme Ultraviolet Explorer Observations of λ Andromedae, ApJ, 554, 1079

Sanz-Forcada, J., Brickhouse, N. S., & Dupree, A. K. 2001b, Quiescent and Flaring Coronal Structure in RS CVn Stars, in Stellar Coronae in the Chandra and XMM-Newton Era, ASP Conf. Series, eds. F. Favata and J. Drake, in press

Sanz-Forcada, J., Brickhouse, N. S., & Dupree, A. K. 2001c, The Structure of Stellar Coronae in Active Binary Systems, ApJ, submitted

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Smith, R. K., Brickhouse, N. S., Liedahl, D. A., & Raymond, J. C. 2001, Collisional Plasma Models with APEC/APED: Emission-Line Diagnostics of Hydrogen-like and Helium-like Ions, ApJ, 556, L91

Conferences Attended during the Reporting Period

Dr. Brickhouse:

AAS High Energy Astrophysics Division Meeting, Honolulu, HI, Nov 2000

Stellar Coronae in the Chandra and XMM-Newton Era, Noordwijk, the Netherlands, July 2001 (invited)

Continuing the Challenge of EUV Astronomy: Current Analysis and Prospects for the Future, Jenner, CA, July 2001 (invited)

Cool Stars 12 Workshop, Boulder, CO, July 2001

X-Ray Astronomy School, Greenbelt, MD, Sept 2001